UNCLASSIFIED

AD NUMBER
AD491977
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; SEP 1951. Other requests shall be referred to Office of Naval Research, One Liberty Center, 875 North Randolph Street, Arlington, VA 22203-1995.
AUTHORITY
ONR notice, 27 Jul 1971

THIS PAGE IS UNCLASSIFIED

49/977

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

Reference No. 51-70

MARINE METEOROLOGY

A Preliminary Analysis of the Vertical Heat Flux at Five Meters over Water

By

H. A. Panofsky

Technical Report No. 13
Submitted to the Office of Naval Research
Under Contract N5onr-27702 (NR-082-021)

September 1951

APPROVED FOR DISTRIBUTION [signature]

Introduction

The members of the Marine Meteorology Project of the Woods Hole Oceanographic Institution have designed equipment for the measurement of the vertical heat flux. This consists of a small vertical vane, a heated thermistor anemometer, and a bead thermister thermometer, all mounted within about 20 centimeters of each other. The instruments were described in detail by Parson and Bunker[1]. The anemometer was not temperature compensated, so that the wind speed itself is possibly not very accurate[2]; however, the wind speed enters the computation of the heat flux only through the vertical velocity, which is not sensitive to errors in the horizontal speed.

The heat flux is given by the equation:

$$F = \overline{\rho c_p \Delta T \Delta w} \tag{1}$$

Here ρ is the density, c_p the specific heat at constant pressure, Δw the deviation of the vertical velocity from its arithmetic mean over a given period of observation, and ΔT is the deviation of temperature from its mean over the same period. The bar over the whole expression denotes an arithmetic mean over the period.

In their recent work, Parson and Bunker obtained the product of vertical velocity and temperature automatically by a computer;

---

1 "A recording Computer for the Direct Measurement of the Turbulent Heat Exchange in the Atmosphere", by Donald Parson Jr. and Andrew F. Bunker. Paper read before the Cambridge Turbulence Symposium, June 1951, to be published in Geophysical Research Papers.

2 "A Wind Tunnel Investigation of the Limitations of Thermistor Anemometry" by Edward R. Sanford. Journal of Met., VIII, pp. 182-190, 1951.

however, several of the older series of observations give the vertical velocities and temperatures explicitly, so that a crude spectral analysis is possible, similar to the analysis of observations made at Brookhaven[3].

Several reasons for such an investigation can be given:

1. A hypothesis advanced by the author[3] concerning the spectral distribution of kinetic energy and vertical flux should be tested at low levels. So far, tests have been made only near 100 meters elevation.

2. Some evidence should be obtained as to whether the observations are read off at sufficiently frequent intervals, and whether the instruments are sensitive to sufficiently short-period fluctuations of the meteorological variables.

3. It should be decided whether the flux has been averaged over a sufficient length of time.

4. In some instances, heat appears to flow against the gradient of potential temperature. The reality of this observation should be tested.

The Observations

Observations of vertical velocity and temperature were available for a number of periods, each lasting 4 to 5 minutes during three days in the summer of 1949. The instruments were mounted on an underwater rock in the Woods Hole harbor 5 meters above the surface.

3 "The Structure of the Stress at 100 Meters at Brookhaven" by H. A. Panofsky. Paper read before the Cambridge Turbulence Stmposium, June 1951, to be published in Geophysical Research Papers.

Table I gives some of the relevant weather characteristics during these periods.

TABLE I

Weather Characteristics During Periods Under Discussion

Situation No.	Date	Time	Wind Dir.	Wind Speed m sec^{-1}	Vertical Variation of pot. temp. 10^{-4} 0 Cm^{-1}
1	July 28	1930	SW	5	1.7
2	Aug. 8	1405	S	6	3.4
3	Aug. 8	2200	S	7	3.4
4	Aug. 8	2300	S	6.5	3.4
5	Aug. 17	0000	NW	5	-2.0
6	Aug. 17	0500	NW	5	-2.0

The last column is based on temperature measurements at two and ten meters. These were read only once during each day, and therefore the exact values are not reliable, although the weather situations showed no considerable changes.

During each of the periods, vertical angle, temperature and horizontal speed were read every second, and vertical velocity was computed and corrected so that the average during the period would be zero. Since the vertical vane has a free period near one second, it seems likely that the shortest fluctuations of vertical velocity indicated are greatly modified by resonance. The temperatures were read to tenths of degrees centigrade in all cases but in situation 2, where the temperatures were read to twentieths of a degree. In situation 3, the temperature variations appeared so slight, that the author reread the original Esterline-Angus temperature records

to hundredths of a degree.

Method of Reduction

The reduction of the data closely followed the procedure described in connection with the Brookhaven observations[3]. Running means of the vertical velocities were formed over 7 and 49 seconds. Then $w''{}'$ was defined as the difference between the observed vertical velocities and the 7 second running means, w'' as the difference between the 7 second and the 49 second running means, and w' as the difference between the 49 second running means and the arithmetic mean over the whole period. Thus, for example, $w''{}'$ measures the part of the vertical velocity due to the shortest period eddies only, and so forth.

From these definitions it follows that :

$$\Delta w = w' + w'' + w''{}' \tag{2}$$

Substitution of equation (2) into (1) yields:

$$F = \overline{\rho c_p w' \Delta T} + \overline{\rho c_p w'' \Delta T} + \overline{\rho c_p w''{}' \Delta T} \tag{3}$$

The three terms on the right of equation (3) will be referred to as the contribution of long, medium and short period turbulence to the vertical heat flux, respectively.

The turbulent double vertical kinetic energy per unit mass is given by: $\overline{\Delta w^2}$. This will be referred to simply as the double energy. With the aid of equation 2, the double energy may be written:

$$2E = \overline{\Delta w^2} = \overline{w'^2} + \overline{w''^2} + \overline{w''{}'^2} + X \tag{4}$$

where X is composed of products of vertical velocity components of

different scale. If w', w'' and w''' had been defined rigorously in terms of definite mutually exclusive groups of harmonics of the vertical velocity, X would be zero; however, the method of running means does not accomplish such an ideal separation of scale, so that X is usually of order 10% of the double energy. For the present set of data, X was always positive.

The first three terms on the right of equation (4) will be referred to as the contributions of long, medium and short period turbulence to the double energy, even though the sum of these three terms is not quite equal to the total double energy.

Analysis of Turbulent Kinetic Energy

Table II gives the observed double energies in the six situations as well as the contributions of the various groups of periods. It should be pointed out that the total observed double energy is by no means the true total energy; for variation of vertical velocity with periods less than a second cannot be measured, yet may contribute significantly to the total energy, especially at levels near the ground.

TABLE II

Spectral Analysis of Double Energy, in $10^2 cm^2 sec^{-2}$

Situation	Total Obs.	Long	Medium	Short	
1	1.6	0.2	0.4	0.8	STABLE
2	4.2	0.2	1.6	2.2	STABLE
3	8.4	0.4	1.8	5.5	STABLE
4	9.3	0.3	3.3	5.3	STABLE
5	5.4	0.5	2.3	1.2	UNSTABLE
6	3.1	0.6	1.8	0.5	UNSTABLE

The table shows that the maximum contribution to the total energy comes from the central group in the last two situations, but from the short period group in the first four situations. This difference is associated with the fact that the stratification was stable in the first four situations, unstable in the last two. The fact that relatively long period oscillations are relatively important when the air is unstable was noted first by Giblett[4], and later by Paeschke[5].

It seems possible that the short period kinetic energy is over-estimated due to the resonance of the vertical vane; however, this effect can hardly be sufficient to produce entirely the overwhelming magnitude of the short period fluctuations under stable conditions. For unless the short period fluctuations are strong to begin with, the vertical vane would not be brought into resonance at all.

It is interesting to note that the greatest total energy does not occur with instability. At low levels, the vertical energy is dependent almost entirely on the wind and the roughness elements; only at much higher levels does stability suppress the vertical oscillations to a considerable extent.

The data indicate a slight positive correlation between

4 "The Structure of the Wind over Level Country" by M. A. Giblett and others. Geophysical Memoirs, Royal Meteorological Office, No. 54, pp. 1-119, 1932.

5 "Experimentelle Untersuchungen zum Rauhigkeits und Stabilitätsproblem in der bodennahen Luftschicht" by Paeschke W., Beiträge zur Physik der freien Atmosphäre, XXIV, pp. 163-189, 1937.

total observed energy and wind speed. Situations 3 and 4 are characterized by much greater energy than the others, even though the wind is only slightly faster; this may be due to transition from smooth to rough sea at wind speeds near 6 m sec^{-1} (Sverdrup[6]).

Analysis of the heat flux

Table III shows the observed vertical heat flux as well as the contribution to it by the different turbulence scales. A plus sign indicates upward flux, a negative sign, downward flux. It is immediately apparent from a comparison of Tables I and III that the heat flux in situations one and three is directed against the gradient of potential temperature. In the other four cases, the heat flows from high toward lower potential temperature.

TABLE III

Analysis of the Heat Flux, 10^{-4}cal $cm^{-2}sec^{-1}$

Situation	Total Obs.	Long	Medium	Short	
1	2.1	1.8	0.4	-0.1	STABLE
2	-3.0	-0.7	-2.4	0.0	
3	1.3	0.7	0.4	0.2	
4	-0.3	0.05	-0.3	-0.05	
5	5.2	1.0	2.8	1.3	UNSTABLE
6	3.8	1.2	2.3	0.3	

In general, the heat flux is characterized by maximum contributions from medium and long period turbulence. Thus, the contributions to

6 "Oceanography for Meteorologists" by H. U. Sverdrup. Prentice Hall, New York, p. 120, 1942.

the flux come from larger scale turbulence than those to the energy. This result agrees with a conclusion drawn from the Brookhaven observations[3].

The maximum contribution to the heat flux in the two unstable situations comes from eddies with periods of twenty to thirty seconds. The distribution given in the table for situations 5 and 6 is affected relatively little by observational peculiarities such as resonance of the vanes; for, in these cases, a relatively small fraction of the kinetic energy is contained in the short periods, and even casual inspection of the vertical angle record indicates that no resonance with periods of order of one or two seconds exists.

The interpretation of the results obtained for the stable situation is complicated by the unreliability of the contribution from the shortest eddies. This is due to the fact that most c the vertical kinetic energy lies at high frequencies, producing uncertainties in two ways: first, the resonance between the air motion and the vertical vane may throw the vane completely out of phase with the air motion; and second, the eddies mostly responsible for the flux are sc small that the distance of some twenty centimeters between the vertical vane and the temperature element no longer permits assignment of the temperature and vertical velocity variations to the same air parcel. It is little wonder therefore that the apparent correlations between short period temperature and velocity variations is negligibly small, as indicated by the last column of Table III. The true correlation at a point may be quite considerable.

A tentative interpretation of the first four lines of Table III is possible with the aid of Priestley and Swinbank's theory[7]. Accordingly, the vertical heat flux may be written:

$$F = -c_p K \rho \frac{\partial \theta}{\partial z} + P \tag{5}$$

Here, K is the heat exchange coefficient, θ the potential temperature and z the height. P is the additional term introduced by Priestley and Swinbank. It arises from the fact that warm air is more likely to rise than sink. Little is known concerning K and P, excepting that both are positive. Therefore, understable conditions, the heat flux consists of two contributions of opposite sign. Table III indicates a possibility of assigning different spectral characteristics to the two terms, which might eventually lead to their separation. In the four stable situations, the contribution of long period turbulence is algebraically larger than that of the medium and short period turbulence. Since the Priestley-Swinbank term P is always positive, this observation makes reasonable the hypothesis that P is produced largely by long period turbulence, with periods of order of a minute. On the other hand, the potential temperature gradient term, which is negative under stable conditions, is produced by higher frequency oscillations.

As a consequence of this hypothesis, the reality of the sign of the total heat flux situation 3, and perhaps even situation 1,

7 "Vertical Transport of Heat by Turbulence in the Atmosphere" by C. H. B. Priestley and W. C. Swinbank. Proceedings of the Royal Society, A, CLXXXIX, pp. 543-561, 1947.

is quite uncertain. For if the negative first term of equation (5) originates mostly from high frequencies, the observational difficulties prevent a reliable estimate of it. In other words, there is an observational bias toward the positive low frequency Priestley-Swinbank term. Whether observations with more quickly reacting instruments would reverse the sign in situations 1, 3, or both, cannot be decided on theoretical grounds.

As a conclusion, the measurement of the heat flux under stable conditions at 5 meters elevation requires that the temperature and vertical velocity elements are within a few centimeters of each other, and that they reflect correctly variations in these quantities during as little as half a second.

Comparison of Observations with Working Hypothesis

The author recently put forward a working hypothesis[3] for the vertical velocity spectrum which accounts reasonably well for the spectral distributions of kinetic energy, stress and heat flux near a hundred meters elevation under unstable conditions. This hypothesis indicates that the turbulent eddies responsible for the flux at 5 meters should lie at much higher frequencies than at 100 meters.

Table IV compares the observed and predicted contributions to the double energy in the various period ranges. In order that the hypothesis could be compared with observations, frequency-cutoff values had to be assigned to running means. Thus, a running mean computed over n seconds was assumed to cut off at n seconds. Similarly, subtraction of the simple arithmetic mean from a set of n observations a second apart was assumed to cut off periods greater than 2 n. The reason for the different treatment of a constant

arithmetic mean and an overlapping mean is that differences from arithmetic means contain, to a large extent, the effect of long period fluctuations, whereas differences from running means do not. Also, theory of time series indicates that nothing is known about fluctuations with periods less than two seconds, if observations are taken every second.

TABLE IV

Comparison of Computed and Observed Spectral Distribution of Double Energy, 10^2 cm^2 sec^{-2}

Situation	Long		Medium		Short		Tot. Obs.	Tot. est. all frequ.
	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.		
1	0.3	0.2	0.8	0.4	0.3	0.8	1.6	1.8
2	0.5	0.2	2.3	1.6	1.2	2.2	4.2	5.0
3	0.5	0.4	4.0	1.8	3.1	5.8	8.4	10.7
4	0.7	0.3	4.8	3.3	3.8	5.3	9.3	11.9
5	0.4	0.5	2.2	2.3	1.4	1.2	5.4	6.6
6	0.4	0.6	1.7	1.8	0.8	0.5	3.1	3.6

The standard deviations of the vertical velocities had to be known in order that the hypothetical vertical velocity spectrum could be evaluated. Since the observations cover only a limited frequency range, the complete standard deviation is not observable, but appears as an adjustable parameter. It was adjusted in such a way that the total kinetic energy in the three frequency ranges combined was the same computed as observed.

According to Table IV, the agreement between observed and computed spectral distributions is good only for the two unstable

situations, 5 and 6. In the other four cases too much energy is observed at high frequencies. This may, in part, be due to resonance of the vertical vane. However, the discrepancy is too large to be accounted for entirely in this manner. Also, a similar differe: ce between hypothesis and observations was noted with the Brookhaven data for relatively stable stratification. The reason for the disagreement was discussed previously[3] and is due to the fact that the working hypothesis gives the maximum possible energy at every frequency, which is realized only under unstable conditions.

The last column of Table IV gives also the total double energy, including all frequencies up to infinity, found under the assumption that the working hypothesis is correct. Apparently, the high and unobservable frequencies contribute significantly to the total energy. The working hypothesis also leads to an estimate of the relative contributions of the various spectral regions to the total heat flux. However, this estimate can be used only if the Priestley-Swinbank term P in equation (5) is small, or has the same spectral characteristics as the term involving the potential temperature gradient. As pointed out in the last sections, neither of these conditions is satisfied under stable conditions, and therefore comparison of the observations with the hypothesis is hopeless for situations 1 to 4. On the other hand, under unstable conditions, the Brookhaven observations indicate good agreement of the spectral contributions to the momentum flux with those of the heat flux; moreover, the hypothesis agrees well with these contributions. Therefore, a comparison of hypothesis and observations seems in order for situations 5 and 6.

TABLE V

Comparison of Computed and Observed Spectral Contribution to the Heat Flux, 10^{-4}cal cm^{-2} sec^{-1}

Situation	Long		Medium		Short		Tot. Obs.	Tot. Est. all freq.
	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.		
5	2.3	1.0	2.5	2.8	0.4	1.3	5.2	5.7
6	2.2	1.2	1.4	2.3	0.2	0.3	3.8	4.3

The hypothetical distribution contains a parameter which was adjusted so that the total contribution in the three ranges is the same computed as observed.

The agreement between computation and hypothesis is disappointing, with the observed contributions tending toward somewhat higher frequencies than what would be expected from the hypothesis. Although the disagreement is not excessive, better results has been expected after the success of the hypothesis with the Brookhaven observations.

The last column of Table V contains the total heat flux which would be obtained if the hypothesis was valid, and observations extended over all frequencies. Apparently, the frequencies outside of the observational range contributed only about 10% of the total flux. Almost none of this was contributed on the high frequency side, indicating that flux computations could be best improved by extending the observations over a longer period. This remark refers to mostly unstable conditions; with a stable stratification, more frequent observations with more rapidly reacting instruments are required for the determination of a reliable heat flux.

Conclusions

The crude spectral analysis described in this note has led to the following tentative conclusions:

1. The sign and magnitude of the heat flux measured at Woods Hole at 5 meters elevation are reliable under unstable conditions only. Even then, a somewhat longer period of observations is desirable.

2. Up to 25% of the kinetic energy under stable conditions, and about 15% under unstable conditions lies at frequencies too high to be measured with existing instruments.

3. Maximum kinetic energy occurs at higher frequencies than maximum heat flux.

4. The working hypothesis advanced previously accounts well for the vertical energy spectrum under unstable conditions. Under stable conditions, it underestimates the importance of high frequencies.

5. The Priestley-Swinbank correction term contributes mostly at periods of the order of a minute, under stable conditions, whereas, at the same time, much higher frequencies are mostly responsible for the term containing the potential temperature gradient.

<u>References</u>

Giblett, M. A. and others, "The Structure of the Wind over Level Country". Geophysical Memoirs, Royal Meteorological Office, No. 54, pp. 1-119, 1932.

Paeschke, W., "Experimentelle Untersuchungen zum Rauhigkeits und Stabilitätsproblem in der bodennahen Luftschicht". Beiträge zur Physik der freien Atmosphäre, XXIV, pp. 163-189, 1937.

Panofsky, H. A., "The Structure of the Stress at 100 Meters at Brookhaven". Paper read before the Cambridge Turbulence Symposium, to be published in Geophysical Research Papers, June 1951.

Parson, D. Jr. and A. F. Bunker, "A Recording Computer for the Direct Measurement of the Turbulent Heat Exchange in the Atmosphere". Paper read before the Cambridge Turbulence Symposium, to be published in Geophysical Research Papers, June 1951.

Priestley, C. H. B. and W. C. Swinbank, "Vertical Transport of Heat by Turbulence in the Atmosphere". Proceedings of the Royal Society, A, CLXXXIX, pp. 543-561, 1947.

Sanford, E. R., "A Wind Tunnel Investigation of the Limitations of Thermistor Anemometry", Journal of Meteorology, VIII, pp. 182-190, 1951.

Sverdrup, H. U., "Oceanography for Meteorologists". Prentice Hall, New York, p. 120, 1942.

Technical Report Distribution List — 15 August 1949
ONR Project NR-082-021

Address	Copies
Chief of Naval Research, Navy Department, Washington 25, D. C., Attention: Code 416	3
Director, Naval Research Laboratory, Washington 25, D. C., Attention: Technical Information Officer	9
Commanding Officer, U. S. Navy Office of Naval Research, Branch Office, 346 Broadway, New York 13, New York	2
Commanding Officer, U. S. Navy Office of Naval Research, Branch Office, 844 North Rush Street, Chicago 11, Illinois	1
Commanding Officer, U. S. Navy Office of Naval Research, Branch Office, 1030 E. Green Street, Pasadena 1, California	1
Commanding Officer, U. S. Navy Office of Naval Research, Branch Office, 150 Causeway Street, Boston 14, Mass.	1
Commanding Officer, U. S. Navy Office of Naval Research, Branch Office, 801 Donahue Street, San Francisco 24, California	1
U. S. Navy Office of Naval Research, U. S. Navy 100, Fleet Post Office, New York, New York	2
Department of Aerology, U. S. Naval Post Graduate School, Monterey, California	1
Aerology Branch, Bureau of Aeronautics, Navy Department, Washington 25, D. C.	1
Mechanics Division, Naval Research Laboratory, Anacostia Station, Washington 25, D. C., Attention: J. E. Dinger	1
Radio Division I, Naval Research Laboratory, Anacostia Station, Washington 25, D. C., Attention: M. Katzin	1
Meteorology Section, Naval Electronics Laboratory, San Diego 52, California, Attention: L. J. Anderson	1
Library, Naval Ordnance Laboratory, White Oak, Maryland	1
Bureau of Ships, Navy Department, Washington 25, D. C., Attention: Code 851	1
Bureau of Ships, Navy Department, Washington 25, D. C., Attention: Code 816	1

Address	Copies
Chief of Naval Operations, Navy Department, Washington 25, D. C., Attention: Op-531-E	2
Oceanographic Division, U. S. Navy Hydrographic Office, Washington 25, D. C.	1
Library, Naval Ordnance Test Station, Inyokern, California	1
Office of Chief Signal Officer, Engineering and Technical Service, Washington 25, D. C., Attention: SIGGE	1
Meteorological Branch, Evans Signal Laboratory, Belmar, New Jersey	1
Office of Quartermaster General, 2nd and T Streets, S.W., Washington 25, D. C., Attention: Environmental Protection Section	2
Commanding Officer, Cambridge Field Station, 230 Albany St., Cambridge, Massachusetts, Attention: ERHS-1, Mr. Groos	1
Chief of Staff, Headquarters USAF, The Pentagon, Washington 25, D. C., Attention: AFMRS4	1
Headquarters, Air Weather Service, Andrews Field, A. F. Base, Washington 20, D. C., Attention: Director Scientific Services	2
Commanding General, Air Material Command, Wright Field, Dayton, Ohio, Attention: MCREEO	1
National Advisory Committee of Aeronautics, 1500 New Hampshire Avenue, N.W., Washington 25, D. C.	2
U. S. Weather Bureau, 24th and N St., N.W., Washington 25, D. C., Attention: Scientific Services Mission	4
Committee on Geophysics and Geography, Research and Development Board, Washington 25, D. C.	2
Air Coordinating Committee, Subcommittee on Aviation Meteorology, Room 2D241, The Pentagon, Washington 25, D. C.	1
Department of Meteorology, Massachusetts Institute of Technology, Cambridge 39, Massachusetts, Attention: H. G. Houghton	1

Address	Copies
Department of Meteorology, University of Chicago, Chicago 37, Illinois, Attention: H. R. Byers	2
Institute for Advanced Study, Princeton, New Jersey, Attention: J. von Neumann	1
Scripps Institution of Oceanography, La Jolla, California, Attention: R. Revelle	1
New Mexico School of Mines, Box 600, Station A, Albuquerque, New Mexico, Attention: E. J. Workman	1
General Electric Research Laboratory, Schenectady, New York, Attention: I. Langmuir	1
St. Louis University, 3621 Olive Street, St. Louis 8, Missouri, Attention: J. B. Macelwane, S. J.	1
University of Texas, Austin 12, Texas, Attention: J. R. Gerhardt	1
Department of Meteorology, University of California at Los Angeles, Los Angeles, California, Attention: J. Bjerknes	1
Institute of Geophysics, University of California at Los Angeles, Los Angeles, California, Attention: J. Kaplan	1
Department of Meteorology, New York University, New York 53, New York, Attention: B. Haurwitz	1
Department of Engineering, University of California at Los Angeles, Los Angeles, California, Attention: L. M. K. Boelter	1
Cornell Aeronautical Laboratory, 4455 Genessee St., Buffalo 21, New York, Attention: S. Chapman	1
Department of Physics and Meteorology, Florida State University, Tallahassee, Florida, Attention: W. A. Baum	1
Blue Hill Observatory, Harvard University, Cambridge, Mass., Attention: C. F. Brooks	1
Department of Meteorology, University of Washington, Seattle 5, Washington, Attention: P. E. Church	1
Laboratory of Climatology, Johns Hopkins University, Seabrook, New Jersey, Attention: C. W. Thornwaite	1

Address	Copies
Armed Forces Special Weapons Project, P. O. Box 2610, Washington 25, D. C., Attention: Blast Branch	1
Air Training Command, Extension Course Unit, 3345 Technical Training Group, Chanute Air Force Base, Illinois	1
Radio Propagation Laboratory, National Bureau of Standards, U. S. Department of Commerce, Washington 25, D. C.	1
Office of the Chief, Chemical Corps, Research and Development Division, Army Chemical Center, Maryland	2

Additional Distribution List

Person or Organization	
Brookhaven National Laboratory, Upton, L. I., New York Meteorology Group	1
Chief, Meteorological Division, Biological Department, Chemical Corps, Camp Detrick, Frederick, Maryland	1
Library, U. S. Weather Bureau, 24th and M Streets, N.W., Washington 25, D. C.	1